Performance Analysis of Coffee Husk with Nano-SiO_2 Particles Reinforced Unsaturated Polyester Composites

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Abstract

Nowadays, there is an increasing concern toward substituting pollutant and non-renewable synthetic fiber, and the scarce wood fibers with alternative lignocellulosic fibers that originate from agricultural residues to reinforce bio-composites. Therefore, many industries are seeking more eco-friendly materials that will decrease the level of environmental contamination and economic cost. The use of bio-based materials for the production of biocomposites is of interest due to their low cost, abundance, and the fact that they are renewable and biodegradable. Coffee is one of the most valuable primary products in the world trade and a central and popular part of Ethiopian culture. However, coffees productions generate a lot of coffee wastes and by-products, which, could be used for more applications. This research work has aimed at evaluating the performance of coffee husk powder with nano-silica reinforced unsaturated polyester composites. To investigate the performance of this composite the coffee husk was crushed, treated with 5% NaOH and dried naturally. Both treated and untreated coffee husk powder was used to produce the composite and tested. The composites were prepared as (15/85, 20/80, 25/75) weight composition for both treated and untreated coffee husk powder, the nano-silica was used 20/80 %wt of treated coffee husk. The results showed that the treated coffee husk has higher performance than the untreated coffee husk composite, while the addition of nano-silica improved the impact strength on contrary it decreased the tensile strength. The result indicates that treated coffee husk fiber can be used in composites as filler to decrease material cost. On this basis using coffee husk fiber is advantageous in decreasing cost and decrease wastes that come from coffee production. Generally treated coffee husk fiber is advantageous reinforcement to increase mechanical properties and decrease cost of the product.

Keywords: *Polyester resin, Agro-waste, coffee husk, bio-composite, thermoset, composite*

1. Introduction

A strong increase in environmental concerns has arisen in the last years. This fact, together with the continuous increase in petroleum prices and the overall depletion of fossil fuels, has encouraged researchers to develop new environmentally friendly materials [1]. A composite material in its essence is a combination of two or more different materials that are mechanically bonded together. Each of the various components retains its identity in the composite and maintains its characteristic structure and properties. The composite materials, however, generally possess combination of properties such as stiffness, strength, weight, high temperature performance, corrosion resistance, hardness and conductivity which are not possible with the individual components [2].

Substantial pressure on standing forest resources, desire to use biodegradable materials, as a result of growing demand in forest industry due to growing population and new application area has encouraged investigators to find solutions. One of the solutions is to employ other alternatives including agricultural residues that are excellent materials to substitute wood and synthetic fibers because they are abundant, widespread, and easily accessible; besides, utilization of agricultural residues advantages is beneficial economically, environmentally, and technologically [3]. Common fiber reinforced composites are composed of fibers and a matrix. Fibers are the reinforcement and the main source of strength whereas matrix glues all the fibers together in shape and transfers stresses between the reinforcing fibers. Sometimes, filler might be added to smooth the manufacturing process, impact special properties to the composites, and / or decrease the product cost [4].

Natural fibers reinforced polymer composites have their several advantages such as low weight, low cost, high availability, easy productivity, their friendly to environment and high specific mechanical performance. Natural fibers confirm advanced mechanical properties like stiffness, flexibility, and modulus composite to glass fibers [5]. Their availability, renewability, low density, and price as well as acceptable mechanical properties make natural fibers more attractive ecological alternative to glass, carbon and manmade fibers used for the manufacturing of composites [6]. Researchers found that when coffee silver skin introduced in bulk enhances elastic modulus while reducing strain. They used CSS treated and untreated and polyethylene as matrix and modified polyethylene as binding agent. Treated coffee silver skin decreases water uptake and improve the bonding[7]. The use of coffee husk increases thermal stability and decreases crystallinity with little effect on mechanical properties[8]. The effects of alkali treatment relative to the tensile and flexural mechanical properties of Colombian coffee silver skin fiber using manual layup manufacturing. Alkali treatment increases surface roughness which leads to better mechanical coupling [9].

Researchers investigated the effects of silane treatment on spent coffee ground which shows better bonding as a result tensile and torsion properties are improved [10]. Alkaline treatment or mercerization is one of the most used chemical treatments of natural fibers when used to reinforce thermoplastics and thermosets. The important modification done by alkaline treatment is the disruption of hydrogen bonding in the network structure, thereby increasing surface roughness. This treatment removes a certain amount of lignin, wax, and oils covering the external surface of the fiber cell wall, depolymerizes cellulose and exposes the short length crystallites [11]. Impressive enhancement of material properties achieved with the inclusion of submicron-size fillers in elastomers has stimulated active research. Clay Nano-composites, especially nano-clay/polymer composites, exhibit dramatic increases in modulus, strength, barrier properties, flammability resistance, and heat resistance compared with conventional composites [12].

The researches focused on spent coffee grounds to change in to usable products like particle boards. The coffee husk composite is barely investigated with thermoplastic matrix composite while there is no research done on thermoset matrix composite using coffee husk.

2. Materials and methods

2.1 materials

2.1.1.Unsaturated polyester

For this research work, researcher used polyester resin as matrix with a brand name of TOPAZ-1110 TP, is a medium reactive unsaturated polyester resin based on phthalic anhydride, with excellent laminating properties, which is purchased from the local world fiber glass supplier in Addis Ababa, Ethiopia.

2.1.2.Hardener

Unsaturated polyester resin is cured by adding a catalyst, which causes a chemical reaction. The catalyst initiates the chemical reaction of the polyester resin and monomer ingredient from liquid to solid state. Therefore, the hardener (curing agent) used for this specific research work is hardener with a brand name methyl ethyl ketone peroxide (MEKP) hardener, which is purchased from world fiber glass supplier in Addis Ababa, Ethiopia.

2.1.3. Mold release

Release wax is a chemical agent used to stop the bonding of the molding material with the mold. Mold release wax is used in casting and prevents the part from attaching to the surface of the mold. Mold release is essential for preventing the polyester from sticking to the mold when the composite is apart. Even though, there are several types of mold release used depending on the mold material and desired characteristics of the finished part, the most common type and used for this research work is HONEY WAX 250 purchased from world fiber glass Addis Ababa, Ethiopia.

2.1.4. Nano silicon dioxide

Nano-SiO_2 is a white fluffy powder composed of high purity amorphous silica powder. Because of its small particle size, nano-SiO_2 had the advantages of large specific surface area, strong surface adsorption, large surface energy, high chemical purity, and good dispersion. This material is purchased from India mart produced by Intelligent Materials Pvt. Ltd.

2.1.5. Sodium hydroxide

Sodium hydroxide, also known as lye or caustic soda, has the molecular formula NaOH and is a highly caustic metallic base. Pure sodium hydroxide is a whitish solid, which is available in pellets, flakes, granules, and as a 50% saturated solution. Sodium hydroxide is used in many industries, mostly as a strong chemical base in the manufacture of pulp and paper, textiles, drinking water, soaps, and detergents. In this research work researchers used NaOH in pellets form, purchased from local supplier **(Sida general trading)** with the product code of, 04897. At room temperature, sodium hydroxide is a white crystalline odorless solid that absorbs moisture from the air. Sodium hydroxide solution appears as a colorless liquid denser than water.

2.1.6.Mold

The pattern is made up of wood with 400*300*5 and it contains the basic parts, box, and cover frame. The cover and Base surfaces of the mold and the walls are coated with mold release wax and allowed to dry. The functions of cover plate are to cover, compress the fiber after the polyester mixture is poured, and to avoid the debris from entering the composite parts during the curing time.

2.2 Methods

2.2.1.Coffee husk preparation

The coffee husk used in this project purchased from Wolaita zone, Ethiopia which is dry processed and fresh. Raw coffee husk crushed with grinder and sieved, after that it will be treated with sodium hydroxide as follows.

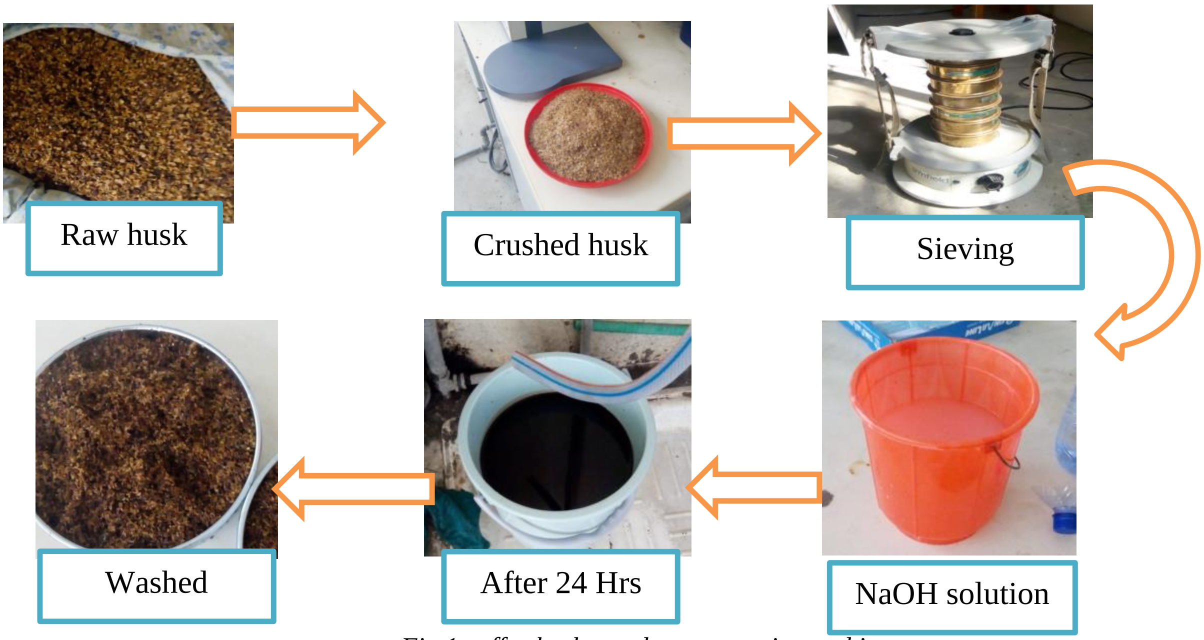


Fig.1 coffee husk powder preparation and its treatment

(a) **(b)**

Fig. 2 a) untreated coffee husk b) treated coffee husk

The coffee husk crushed using PX-MFC 90 D to the grit size of 0.25 – 2 mm. The coffee shell fiber separated in size of fiber length using sieve. After that some of the coffee husk fiber treated with sodium hydroxide with 5% composition for 24 hours, and washed with tap water. The coffee husk fiber dried using natural sunlight for three days. The coffee shell powder, polyester resin, hardener, and nano silica mixed homogeneously in different proportion. Then the mix removed from mixing bowl and cooled in a mold in different proportion of coffee shell and polyester resin as well as nano silicon dioxide. The weight percentage composition of fiber to coffee husk is as follows (85/15, 80/20, 75/25) for treated and untreated, and the treated coffee husk fiber reinforced epoxy composite with nano-silica weight composition is as follows (79/20/1, 77/20/3, 75/20/5). From those nine different samples are manufactured. Finally, the composite will be ejected from the mold after 24 hours.

Fig. 3 a) mixing coffee husk and polyester b) unsaturated polyester resin

Fig. 4 Prepared tensile samples under controlled environment

Fig.5 Failed specimens during tensile test

2.2.2.Pendulum impact test

The Charpy impact test, also known as the Charpy V-notch test, is a high strain rate test that involves striking a standard notched specimen with a controlled weight pendulum swung from a set height. The impact test helps measure the amount of energy absorbed by the specimen during fracture.

Fig. 6 prepared impact samples

2.2.3.Water absorption test

Samples was prepared in dimension (30*25*5) mm, the specimens was kept dry in room temperature, then the dry weight is measured and inserted in tap water. It was covered to remove the entrance of dirt and other substances it was measured continuously in 24 hours difference for three consecutive days.

Fig. 7 water absorption test samples and water absorption test respectively

2.2.4.Hardness test

Hardness is a measure of a material's resistance to localized plastic deformation. A small indenter is forced into the surface of a material to be tested, under controlled conditions of load and rate of application. The depth or size of the resulting indentation is measured, which in turn is related to a hardness number; the softer the material, the larger and deeper the indentation, and the lower the hardness index number. In this case hardness test is conducted using Vickers hardness test, Vickers (sometimes also called diamond pyramid). For each test a very small diamond indenter having pyramidal geometry is forced into the surface of the specimen. The resulting impression is observed under a microscope and measured; this measurement is then converted into a hardness number [13]. To conduct this test ASTM D570 followed. The test was conducted in materials engineering laboratory using HVS50 harness testing machine.

2.2.5.Microstructure observation

The microstructure observation is conducted using scanning electron microscopy in Biology laboratory, using **JCM-6000Plus** scanning electron microscopy. The specimen preparation considers the sample's size, shape, state, and conductive properties prior to sample preparation. The samples prepared with 20 mm diameter and 5 mm thickness. The samples are cleaned and dried (to avoid water vapor) without changing texture of the sample. Then the samples were mounted and observed.

3. Result and discussion

3.1. Tensile test results

Tensile strength is the ability to withstand pulling force, researchers used to conduct the test using universal testing machine in Ethiopian Conformity Assessment Enterprise. The gauge length was 200mm and the cross head was moving at the speed of the 5mm/min until fracture. The three specimens were tested for each sample and the average value was taken. The entire specimen's failure was due to brittle fracture since unsaturated polyester is highly brittle.

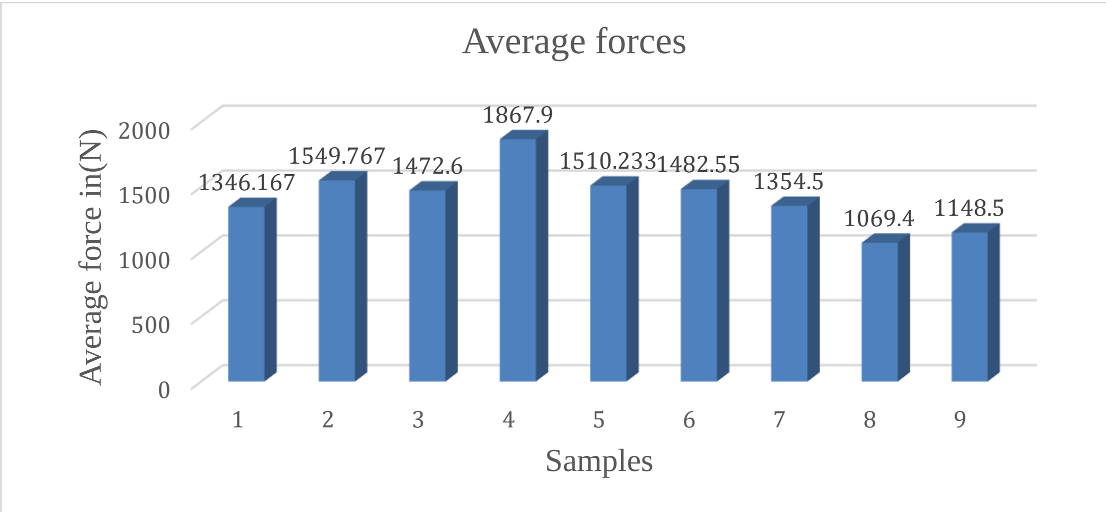


Fig. 8 Average force resisted during the experiment

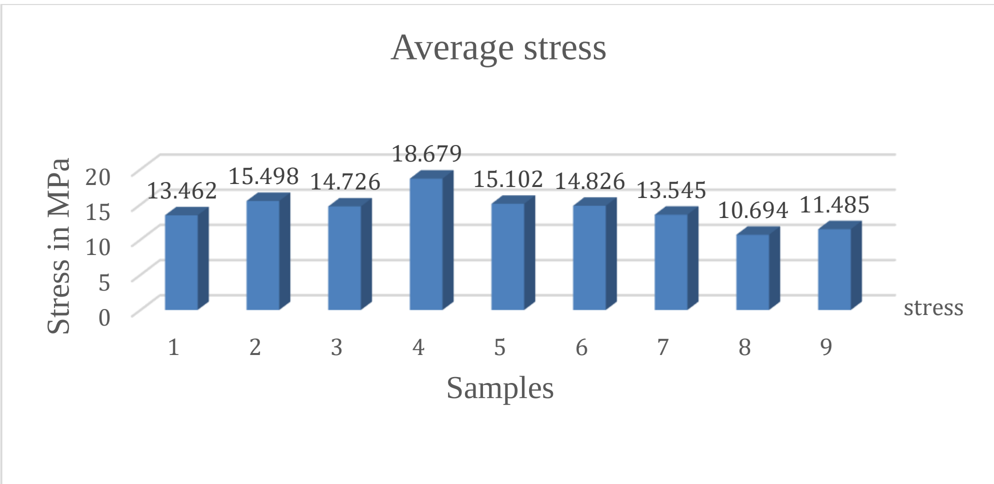


Fig. 9 Average stress

Table 1 Average strain, stress force and Young's modulus of each samples

Samples	Strain @ Break (%)	Stress @ Break (N/mm²)	Force @ Break (N)	Youngs Modulus (N/mm²)
S1	1.625	13.462	1346.17	1472.38
S2	1.851	15.498	1549.77	1467.804
S3	1.523	14.726	1472.6	860.378
S4	1.381	18.679	1867.9	1469.777
S5	1.486	15.102	1510.23	1044.054
S6	1.528	14.826	1482.55	1148.308
S7	1.137	13.545	1354.5	1646.28
S8	0.975	10.694	1069.4	1530.174
S9	0.979	11.485	1148.5	2216.951

The tensile strength of coffee husk polyester nano SiO_2 hybrid composite presented in the above figure 8, the sample four with composition 15% treated coffee husk is the strongest. The maximum force resisted is 1867.9 N and the maximum tensile strength is 18.679 N/mm^2 while the maximum elongation is 1.851% at sample 2. Based on the composition of the coffee husk, polyester resin, and nano SiO_2 the properties also vary. The maximum Young's modulus obtained at sample nine which contains 5% nano silica.

3.2. Impact test result

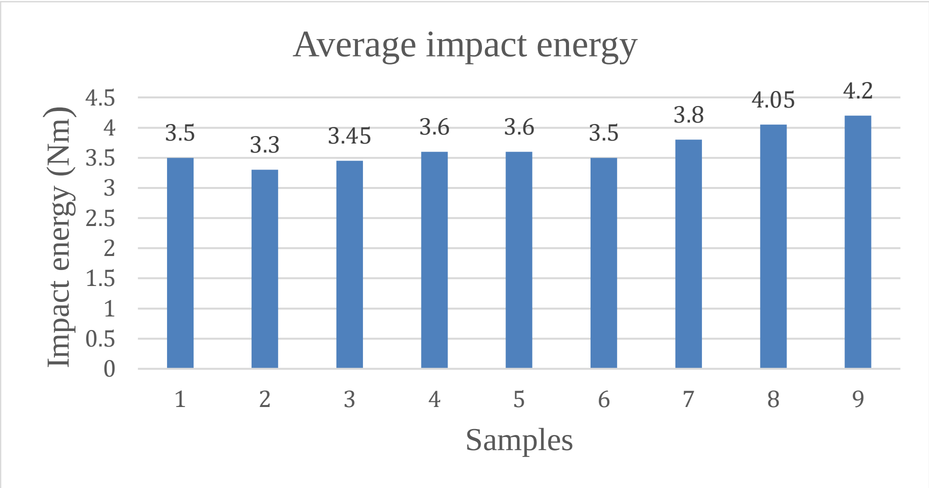


Fig. 10 Average impact energy graph

As shown in the fig.10, the highest impact strength is obtained at sample nine which have compositions of 20% coffee husk, 75% unsaturated polyester resin, and 5% nano silica with impact energy of 4.2Nm, the next one is 20% weight composition of treated coffee husk composites with impact energy of 3.6Nm.

3.3. Water absorption test result

The water absorption of the composite is expressed below graphically. The lowest the water absorption is better so sample four have the lowest water absorption followed by sample nine, sample two, and sample nine.

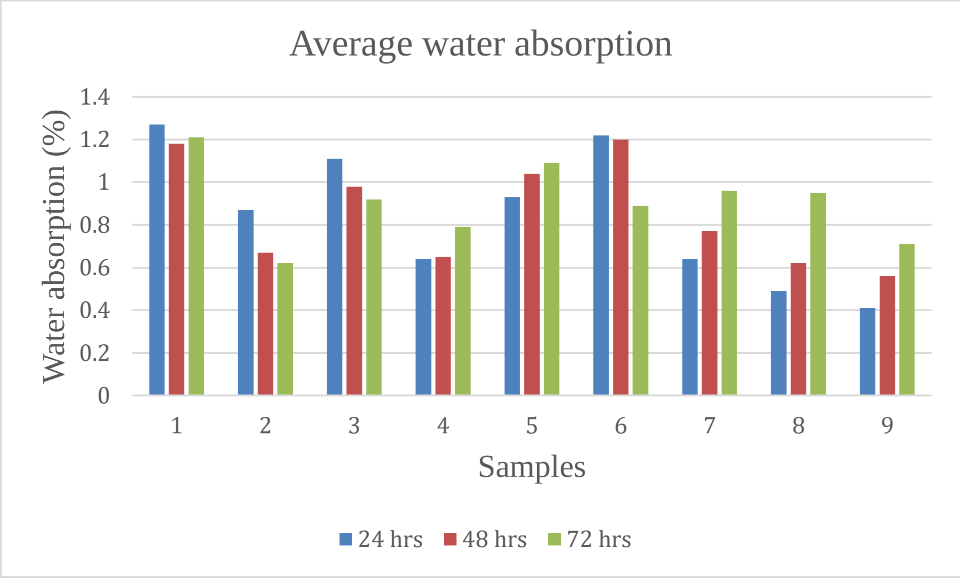


Fig. 11 water absorption of the coffee husk reinforced polyester composite samples.

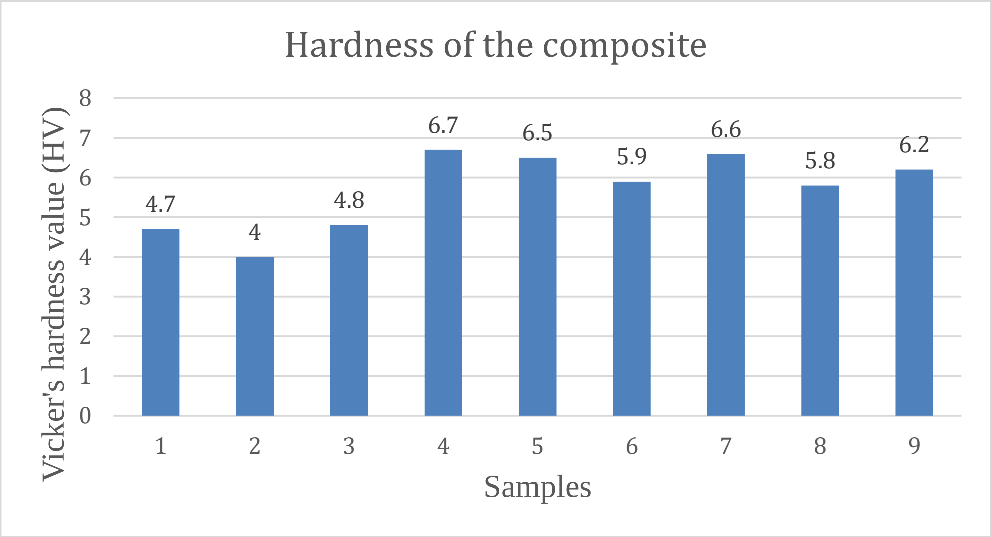
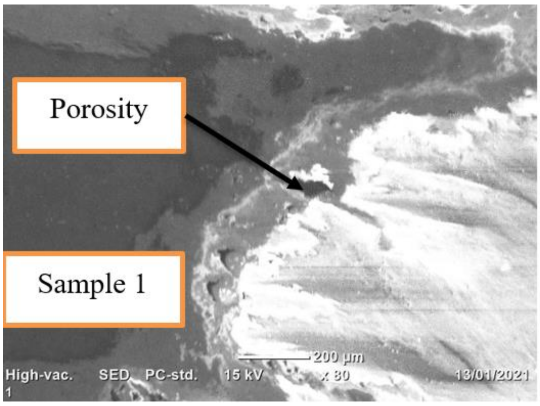


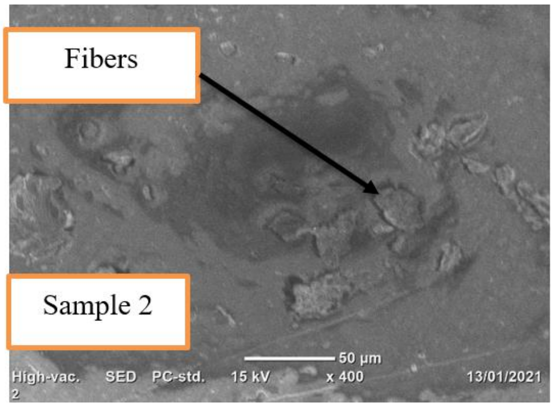
Fig. 12 Vickers's hardness value of samples

It can be seen from the figure 12 that the highest Vickers hardness number is 6.7 from sample four followed by samples seven, five, and nine with Vickers hardness value of 6.6, 6.5, and 6.2 respectively.

3.4. Microstructure result

The microstructure of the coffee husk polyester composite has been seen using SEM and optical microscopy. The images are used to observe the distribution of matrix and substrate powder in the composite, cluster formation, voids, surface cracks, and cracks.





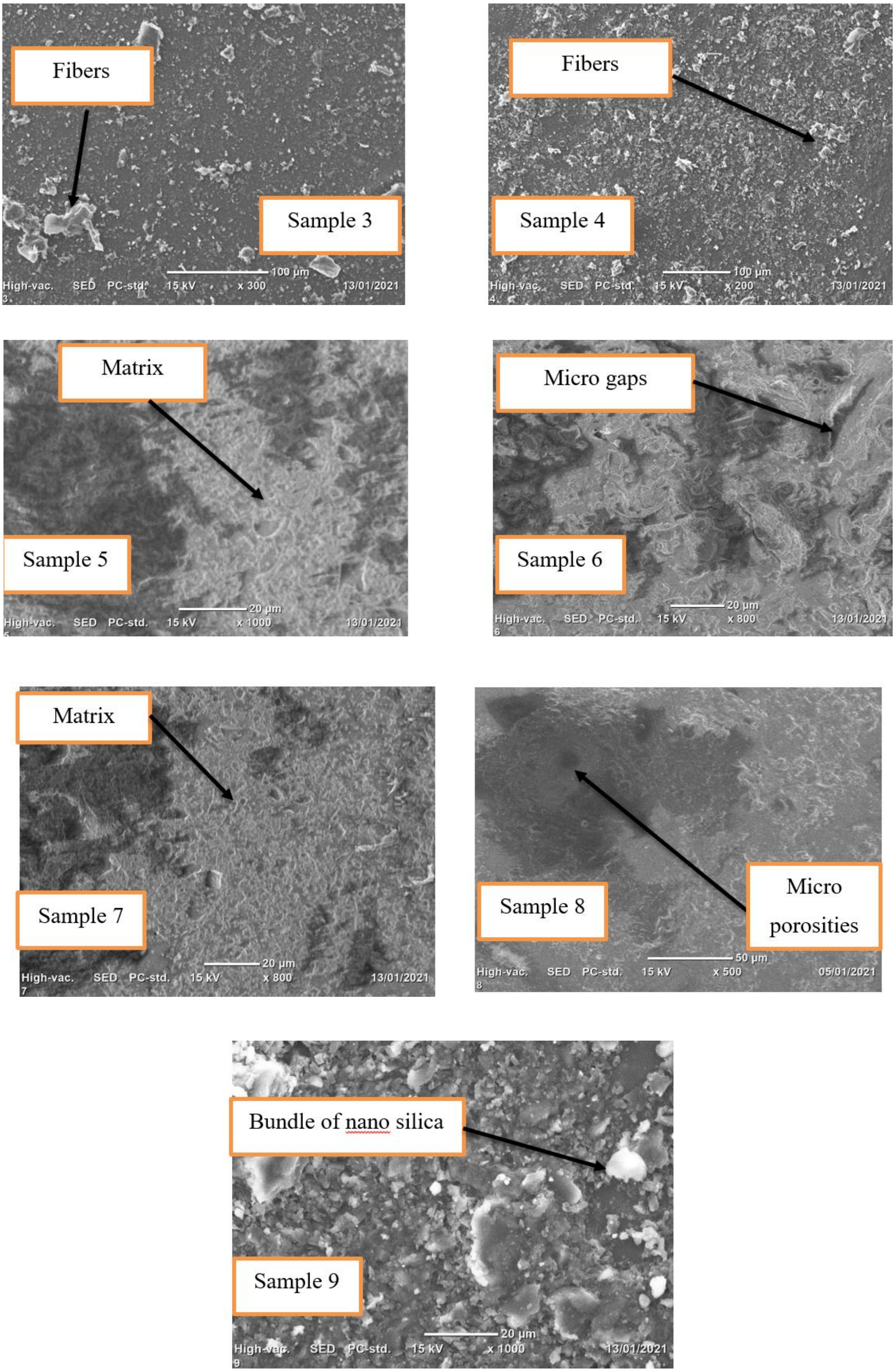


Fig. 13 SEM images of sample 1, 2, 3,4, 5, 6, 7, 8, and 9 respectively

4. Conclusion

Natural fibers and agro-wastes are attracting attention due to their availability, environmentally friendly, cheap, and lightweight. Previous works in this area show the way of incorporation of natural fibers, like jute, sisal, banana, and so on using different matrices like epoxy and polyester. They showed the use of agricultural wastes such as rice husk, coconut husk, stalks, and spent coffee ground as filler and reinforcement. In this work, the researcher investigated the performance of coffee husk and unsaturated polyester resin matrix composite. The coffee husk was purchased from a local supplier and processed to be used in the composite. Then the composite manufactured on nine different composition sets namely, untreated coffee husk reinforcement and unsaturated polyester matrix (15/85, 20/80, 25/75) %wt, with treated coffee husk (15/85, 20/80, 25/75) %wt, and finally treated coffee husk and nano-silica (20/79/1, 20/77/3, 20/75/5) %wt. These sets of samples were experimented with, and finally treated coffee husk (15/85) %wt was found best. But the composites which contain nano-silica has better impact strength compared to other samples. Based on data analysis in the previous chapter confirm that treated coffee husk has superior performance. The addition of nano-silica improved water absorption and impact strength while decreased tensile strength.

Finally, the results confirmed that coffee husk can be used as reinforcement in the unsaturated polyester matrix by using a combination of other natural or synthetic fibers. Sample four is best at tensile strength and water absorption properties. The treated 15/85wt% have been found that 18.67Mpa tensile strength, 6.7 Vickers hardness value, 0.79%wt water absorption, and 3.6Nm impact strength. In terms of micro-structure also sample four is best with uniform distribution of coffee husk fiber without porosity. From all the results and comparisons, the researcher can conclude that the fabricated coffee husk reinforced polyester composite has a good mechanical property and it is recommended to use it for light-load applications including the production of the internal door panel. These composites can be used for indoor applications like false ceilings, windows, bathroom, and furniture.

Generally the treated coffee husk polyester composite is stronger comparative to the thermoplastic matrix composites. So, the treated coffee husk polyester composite is recommended to use in manufacturing composite that can decrease the cost of composite, for indoor application.

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